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Unleashing the input–output exchange opportunities within the fashion ecosystem☆

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A R T I C L E I N F O

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A B S T R A C T

Industrial Symbiosis (IS) has emerged as a key strategy to enhance sustainability and circularity by repurposing industrial waste as inputs for other sectors, creating positive externalities. The fashion industry, including textile and leather goods, generates vast amounts of waste that often go unrecovered, making it a strong candidate for IS adoption. However, existing research mainly focuses on specific resource exchanges or structural characteristics of IS networks, without clearly mapping potential matches. Despite its potential, IS adoption remains limited due to challenges in identifying optimal partnerships. This study addresses this gap by exploring IS opportunities within the fashion sector, identifying input–output exchanges between fashion and other industries. To achieve this, a systematic literature review was conducted to analyse and summarize shared materials and waste flows, clarifying possible synergies. The findings were further investigated through case studies and semi-structured interviews, which confirmed some existing exchanges, revealed previously unknown flows, and uncovered new synergies beyond those documented in the literature. From a theoretical standpoint, this study maps key synergies across value chains in the fashion industry, moving beyond linear exchanges to highlight alternative resource substitutions for new product creation. From a practical perspective, it provides managers with actionable insights to develop effective IS exchanges, enhance waste valorisation, and support a circular economy. Furthermore, this approach is scalable to other industries, such as food, construction, and electronics, where IS networks could optimize resource use, reduce waste generation, and minimize dependence on critical raw materials, supporting broader circular economy strategies.

1. Introduction

The circular economy (CE) concept, although conceptualized in the early 1970 s, has only become an integral part of the economic landscape in the Third Millennium (Despeisse & Acerbi, 2022). It is defined as an industrial economy aiming at reducing resources consumption, extending resource lifecycle, and recirculating materials across subsequent lifecycles (Bocken et al., 2016). This growing trend is becoming increasingly essential to address the rising volume of waste. For instance; in Europe, more than 2.1 billion tons of waste are generated annually (European Parliament, 2024a). To mitigate this issue, several countries have introduced new legislation aimed at extending resources lifecycle and enhancing resources value. An example is Italy's by-products legislation, established by the Decree No. 264 published on 13th October 2016, which outlines criteria for classifying production residues as by-products rather than waste under specific conditions. Among various industries, waste generation and inadequate waste management are particularly critical in the textile sector (Juanga-Labayen et al., 2022). However, the adoption of sustainable product and process practices in this sector can positively impact business competitiveness (Ciarapica et al., 2017; Resta et al., 2018). The textile industry alone produces approximately 53 tonnes of fibre annually for clothing (Ellen McArthur Foundation, 2017), yet only 1 % of used garments are recycled (European Parliament, 2024b). The situation worsens when considering the fashion industry as a whole (Saccani et al., 2023), which consists of two complementary segments: slow and fast fashion (Sellitto et al., 2022). Among them, fast fashion has significantly increased consumer demand, encouraging the purchase of more clothing items than needed, pushing companies to double their production volumes (Neethu & Bhuvaneswari, 2024). In this context,

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Industrial Symbiosis (IS) emerges as a key strategy to reinforce circularity principles by extending resource lifecycles (Neves et al., 2020). First defined by (Chertow, 2000), IS is a subset of industrial ecology consisting of reciprocal interactions among industries to gain competitive advantages through the physical exchange of materials, energy, water, and by-products. IS is considered a practical way to implement the CE, where waste streams from industrial production and related activities are collected, reused, or recycled into valuable resources (Song et al., 2017). It is defined as the physical exchange of resources, including materials, energy, waste and by-products, among industrial actors that do not belong to the same supply chain (Domenech et al., 2019). This fosters mutually beneficial cooperation between industries or entities, enhancing their products and processes. The core objective of IS is to repurpose waste generated by one industry as input for another (Lawal et al., 2021), identifying optimal input–output matches. Also referred to as "symbiotic supply chains", IS facilitates the transfer of unused resources from one company to another, prolonging their lifecycle and transforming them into valuable assets once again (Fussone et al., 2024).

Nevertheless, despite its numerous positive externalities, IS faces several critical obstacles that can slow down or disrupt the entire process (Neves et al., 2020). Many companies struggle to identify suitable matches (Mollica et al., 2024), while information barriers and limited access to sustainable IS opportunities remain key challenges in adopting CE principles (Acerbi et al., 2020; Domenech et al., 2019), and more specifically, IS (Henriques et al., 2021; Yang et al., 2022). To overcome information barriers, collaborative digital platforms can facilitate by-products exchanges within existing networks, serving as decision support systems (Low et al., 2018; Taddei et al., 2022). While research has explored the architectural design of such platforms, existing studies have yet to instantiate specific sectoral matches (e.g., Benedetti et al., 2017; Raabe et al., 2017). Some studies have proposed frameworks for establishing IS networks (Mirata et al., 2024) or optimizing operations within IS networks (Daquin et al., 2023), yet they do not clarify the specific synergies achievable through these networks. Instead, they primarily evaluate challenges and key characteristics (Fric et al., 2025). Moreover, most studies adopt a vertical approach, focusing on waste reuse and management for a specific material. For example, Neri et al. (2021) explored garment reuse for panel production, while Hussain et al. (2021) examined the reuse of mild still material for fabrics. To the best of the authors' knowledge, no comprehensive analysis has yet been conducted on potential synergies between sectors, nor are there studies specifically focused on synergic opportunities between the fashion industry and other sectors in terms of concrete input–output matches (Neves et al., 2020; Sassanelli et al., 2023). Therefore, the research aims to fill this gap by conducting a structured analysis of potential input–output exchanges and evaluating how these matches can be established and fostered in the industrial domain.

To address this research objective, two research questions (RQs) will be addressed:

- RQ1: "*What are the main input–output resource exchanges involving the fashion industry that enable IS networks?*"
- RQ2: "*How can the input–output resources exchanges be established and fostered?*"

To address RQ1 and RQ2, a systematic literature review and semi-structured interviews with practitioners were conducted respectively. RQ1 aims to systematically identify synergic opportunities between the fashion industry and other value chains, ultimately reducing waste in this sector. RQ2 explores empirical evidence on how to foster the adoption of these opportunities, considering the current limited creation and availability of IS networks.

By pursuing these research objectives, both theoretical and practical implications can be achieved. From a theoretical perspective, this study advances knowledge on the adoption of IS as a CE strategy in the fashion industry, identifying key input–output matching opportunities. A detailed list of potential synergies drawn from the existing literature was further analysed through semi-structured interviews with experts, enabling the identification and conceptualization of new synergies. This process also served to validate and integrate those previously fragmented in the literature or not yet widely recognized across industrial actors. From a practical perspective, the study supports practitioners in valorising waste, converting it into inputs for different value chains. This allows fashion waste to be repurposed as an input for other industries, and vice versa. Given its scalability to sectors like food and construction, the study lays the foundation to enhance the adoption of IS, uncover existing but unexplored networks, or facilitate the creation of new ones, fostering deeper industrial collaboration and advancing CE strategies.

The remainder of the paper is structured as follows: Section 2 presents the research methodology; Section 3 outlines the systematic literature review results; Section 4 develops a comprehensive framework, validated through interviews and discussed in detail; Section 5 concludes with the key contributions, limitations and future research opportunities.

2. Methodology

To identify and enhance synergies between the fashion industry and other industrial sectors, a systematic literature review was conducted to analyse the IS adoption within the fashion industry at large, including textile and leather sectors. The review aimed to highlight potential synergies between fashion and other value chains to embrace CE principles. Scopus was selected as the search engine, given its broad coverage and widespread use in industrial engineering research (Ren et al., 2019). The database was queried in February 2025 using the following research string: "*TITLE-ABS-KEY (("circular economy") AND ("waste management" OR "waste exchange" OR "industrial symbiosis") AND ("fashion industry" OR textile OR clothing OR apparel OR garment OR leather OR footwear OR shoe OR bag OR accessor*)) AND (LIMIT-TO (LANGUAGE, "English"))*". This search yielded 321 documents. Publications that broadly discussed waste management or CE without addressing input–output exchanges were screened and excluded, reducing the dataset to 208 papers. A second screening round involved a full-text review, further refining the selection based on inclusion criteria. The focus was on studies explicitly detailing resource exchanges, prioritising those in which inputs, once transformed, generate new outputs for a different industry. This final selection process resulted

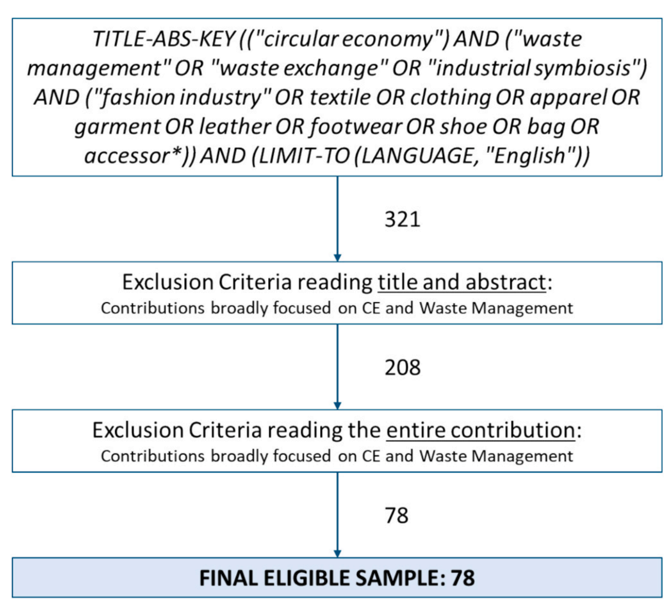

Fig. 1. Literature review screening process.

in 78 eligible publications. Fig. 1 provides a step-by-step overview of the literature review process.

The selected sample of eligible papers was analysed to identify input–output matches and uncover industrial synergies that can be operationalised in collaboration with the fashion sector. This analysis directly contributed to addressing RQ1 "*What are the main input–output resource exchanges involving the fashion industry that enable IS networks?*".

Based on the literature review findings, a framework highlighting the potential input–output matches was developed and further investigated through semi-structured interviews conducted within multiple case studies. To explore the emergent concept of IS, an exploratory case study approach was adopted, as this method is well-suited for investigating new research areas where multiple variables interact and contextual understanding is crucial (Yin, 2014). This methodological choice aligns with prior studies investigating other emerging areas, such as Lean 5.0 (Fani et al., 2024) and the application of blockchain technology in designing and implementing circular economy ecosystems (Ferreira et al., 2023). In particular, we applied theory-based sampling (Suri, 2011), selecting companies which reflect their current or potential involvement in IS networks linked to the fashion ecosystem. The sample included companies already engaged in IS within the fashion industry and those participating in IS networks but not yet strongly connected to the sector, though interested in future collaborations. The focus was on small enterprises, given their well-documented barriers to IS adoption (Akhtar et al., 2022; Patricio et al., 2018), with additional consideration for micro and start-up businesses (Kimuli et al., 2023; Sgambaro et al., 2024). The study was set within the Italian context, following previous research on IS in specific geographic areas (Rincón-Moreno et al., 2020; Ruiz Puente et al., 2015). Initially, 10 small or micro companies were identified, of which 8 were contacted, and 5 agreed to participate in interviews (their company profiles are summarised in Table 1), in line with the sample size of existing studies (Frantz Schneider et al., 2024; Palombi et al., 2024). Two companies were not contacted, as they were already involved in IS networks but had no interest in expanding their collaborations to the fashion industry. Through these interviews, RQ2 "*How can the input–output resources exchanges be established and fostered?*" was addressed by evaluating, based on empirical evidences, the key drivers enabling IS-based synergies. The interviews were conducted between June and July 2024, each lasting approximately 1.5 h. During the semi-structured interviews, participants were asked about synergies between the fashion sector and other industries, their experiences in identifying and establishing IS-based relationships, the methods used to identify cross-sector synergies, and perceived needs for fostering similar network developments (see the interview protocol in Appendix A). Each interview was recorded, transcribed, and independently coded by two researchers to minimize observer bias. After analysing the results, a report was prepared and shared with the companies to support the validation process and collect final feedback for refinement.

Table 1
Company profiles.

Company name	Description	Interviewee	Duration
Company A	Microenterprise pioneering technological innovation by utilising marble powder to develop sustainable products.	Operations and Sustainability Manager	1.15 h
Company B	Microenterprise specialising in eco-friendly bag production, using organic and recycled materials, including pineapple leaves and food industry waste. Handles and external components are made from certified wood, while hidden structural parts incorporate cork, recycled cardboard, natural glue, and waxes.	Operations and Sustainability Manager	1.00 h
Company C	Small enterprise active since 2010 in the textile and chemical industries, producing eco-sustainable materials from vegetable processing waste for the leather, footwear, and paper industries.	Middle Manager involved in sustainability actions	1.30 h
Company D	Start-up in the agricultural and food sectors, transforming spent coffee grounds into recyclable, bio-based thermoplastic materials.	CEO – Operations and Sustainability Manager	1.30 h
Company E	Micro-enterprise in the manufacturing and materials sector (fewer than 10 employees), specialising in upcycling recovered raw materials (e.g., orange peels, lemon zest, coffee waste) into an innovative, 100 % organic, and durable material used to create design objects.	CEO – Operations and Sustainability Manager	1.45 h

3. Literature review results

The literature review was conducted to outline key trends in this research domain through descriptive statistics (i.e., Section 3.1) and qualitative analysis (i.e., Section 3.2). This approach aligns with existing studies (Bucci et al., 2025; Taddei et al., 2022), which similarly combine quantitative assessment with qualitative insights to provide a comprehensive understanding of emerging research areas.

3.1. Descriptive analysis

The 78 contributions identified through the literature review were analysed to assess publication trends over time, evaluating the current research interest and its evolution. Additionally, the most commonly used keywords in the eligible papers were examined and iteratively refined to optimise the Scopus search string. Finally, the most frequently adopted research methodologies were reviewed to determine the dominant analytical approaches, distinguishing between theoretical contributions (e.g., literature reviews) and empirical studies employing specific techniques such as chemical analysis or Life Cycle Assessment (LCA) to identify potential research gaps and future opportunities.

Fig. 2 illustrates the increasing number of publications resulting from the entire research query (i.e., the sum of selected and discarded documents), reflecting a growing interest in the topic over time. This growing attention aligns with the increased awareness of the need for more responsible production and consumption patterns in the fashion sector, particularly in the textile and clothing industries, as emphasised in the CE Action Plan (European Union, 2020). However, when focusing specifically on the selected contributions, a decline in relevant publications is observed in recent years. This is due to the inclusion criteria, which consider only studies explicitly addressing input–output exchanges between industries involved in IS within the fashion ecosystem—comprising the fashion, textile, and leather sectors, as defined based on the results of the literature review (see sub-section 3.2 for details). As a result, more general-purpose contributions, particularly those published in 2024, were excluded from the analysis. For instance, some excluded papers mention the fashion industry as a potential sector for waste recovery but in a broad and generic manner, without detailing specific applications. Examples include studies citing PET waste (Weiland et al., 2024) or research on nanocellulose composites derived from industrial, agricultural, and textile waste, without specifying how these materials integrate into the fashion ecosystem (Azka et al., 2024).

The analysis of keywords used in the eligible papers was conducted to refine the search string and explore potential research streams in greater depth. This step was crucial for gaining a comprehensive

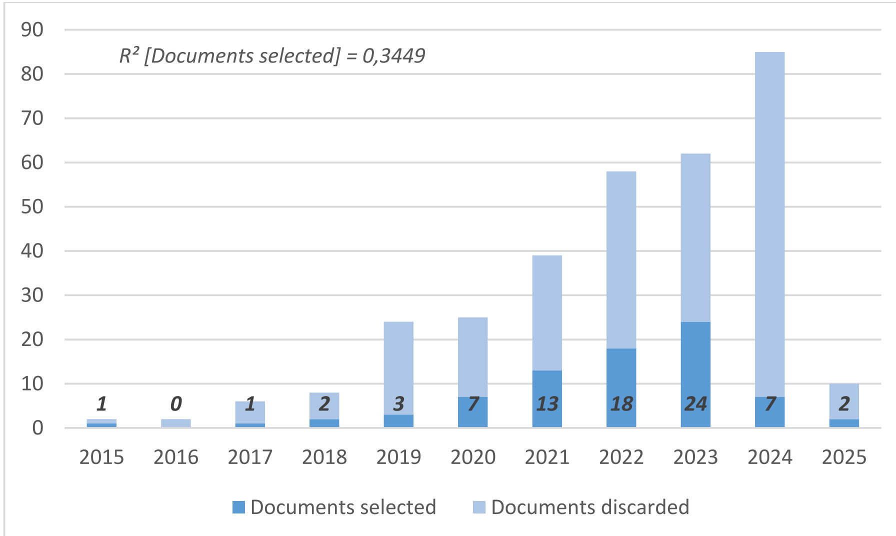

Fig. 2. Contributions published per year (documents selected labelled).

understanding of the research landscape in this field and identifying key themes and significant areas of interest. Keywords represent central concepts addressed by authors in their scientific work and play a vital role in detecting industries potentially involved in resources exchanges with the textile sector. Among the most frequently used keywords, the most recurring terms include "waste," "textile," "management," "recycling," "sustainability," and "circular", as illustrated in Fig. 3, where the size of each keyword is proportional to its frequency. Notably, "textile" appears among the most frequently used keywords in fashion-oriented research, even though the search string also includes related sub-industries, such as leather, footwear, and similar sectors. Additionally, it is interesting to observe that "waste" and "management" are the most prevalent terms in literature when discussing synergistic opportunities. This suggests that the concept of IS is not yet fully established or widely recognized within this research domain.

The types of studies conducted on IS in the fashion sector across the eligible papers are summarized in Fig. 4. The analysis reveals that most contributions are theoretical, primarily based on literature reviews. However, empirical studies, such as chemical analyses, also represent a significant portion, particularly those investigating the chemical transformations of resources and their conversion into new outputs. Although literature reviews remain the most common contribution, in recent years, many have become increasingly generic, often focusing on the structure of IS networks. For example, Mirata et al. (2024) proposed a framework for establishing IS networks, while Daquin et al. (2023) focused on optimizing operations within them. However, only a few studies specifically address input–output exchanges within the fashion ecosystem. Notable examples include Neri et al. (2021), who explored garment reuse for panel production, and Hussain et al. (2021), who investigated the reuse of mild still material for fabric applications. To the best of the authors' knowledge, no existing study provides a comprehensive overview of all potential synergies withing this ecosystem. This underscores the need for a more targeted review that systematically maps and evaluates the specific resource flows between industries, providing a clearer understanding of potential synergies in IS applications.

3.2. Qualitative analysis

The 78 eligible articles were analysed in depth to examine the

Fig. 3. Word cloud of keywords.

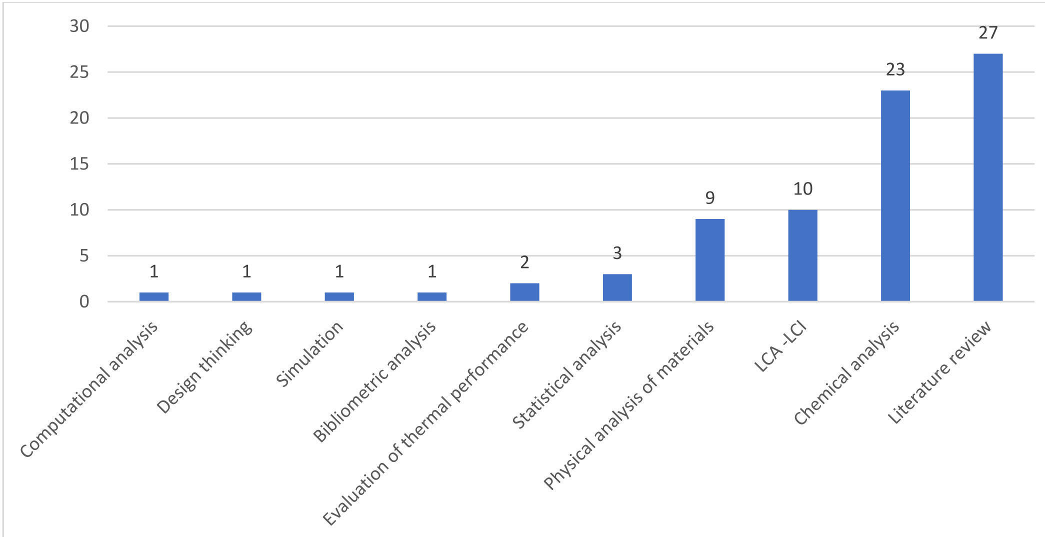

Fig. 4. Number of contributions published per study typology.

input–output flows and identify potential exchanges between the fashion sector and other industrial sectors. Throughout the review process, the sample of papers was clustered mainly into three key areas, as it emerged that the fashion sector is typically analysed through three lenses: the fashion itself, which focuses on finished goods; the textile, encompassing fabrics as raw materials for clothing, as well as yarn production; the leather, considered as a distinct raw material with unique processing characteristics. The following sub-sections present a detailed analysis of all potential exchanges between these fashion-related sectors and external industries, based on insights drawn from the existing literature.

3.2.1. Synergetic industrial interaction between textile and other sectors

The agricultural sector plays a crucial role in IS with the textile industry, contributing to a cooperative ecosystem that promotes resource circularity. Raw palm waste has been used to remove dyes from textile effluents, demonstrating its potential for integrated material management (Azoulay et al., 2022). Similarly, algae serve as bio-sorbents, useful for pollutant removal in textile wastewater and natural dye production (González Fernández et al., 2023). Additionally, fungal mycelium has emerged as an innovative bio-based material applicable in fashion for fabric production (Cerimi et al., 2019).

Conversely, agriculture benefits from textile waste, as seen in biodegradable water-absorbing geocomposites (BioWAGs), which improve soil water retention and plant (Marczak et al., 2023). These innovative materials are designed to retain soil moisture, enhancing plant growth conditions while reducing water consumption in agriculture. Similarly, wool fibre residues, processed into keratin hydrolysate, can be used in microbial growth media, bio-fertilizers, or animal feed, contributing to a sustainable production cycle (Navone et al., 2020).

In the chemical industries, cotton textile fibres can be converted into sugars, then transformed into sugar-based construction blocks (Vera et al., 2023). Chemical and enzymatic treatments allow textile waste to serve as chemical feedstocks (Voncina et al., 2018) or be processed into aromatic hydrocarbons, supporting carbon neutrality and CE goals (Wang et al., 2022).

The construction sector integrates textile waste into various applications. Wool waste, combined with phase change materials, enhances thermal mass in building materials (Rubino et al., 2019). Composite panels from wool waste, chitosan, and gum Arabic serve as sustainable insulation solutions (Antolinc & Filipič, 2021). Nonwoven polyester fabric, obtained directly from the production line as strips and bales, is first shredded into smaller fractions and then compressed using a hot press to create compact thermal insulation panels. Marinelli et al. (2022) describe how cement mortar can be reinforced with recycled synthetic fibres derived from end-of-life artificial turf carpets. The collection of these discarder carpets allows for the recovery of various materials, including plastic fibres used in cement mortar, as well as silica sand, rubber, and bituminous membrane. Textile waste can also be used for vapor barriers and rain screens (Salah et al., 2022). Additionally, Augello et al. (2022) and Biyada et al. (2023) focus on the valorisation of textile waste collected by municipal districts to develop new thermal insulators for building applications.

The energy sector utilises organic textile waste in anaerobic digestion, producing biogas for heat or electricity generation (Kramens et al., 2023). Certain textile wastes can also be converted into pellets, making them a suitable fuel for stoves and boilers (Lu et al., 2022).

The food sector provides bio-based resources for textile production. Dried corn husks are transformed into natural pigments for fabric dyeing (De Nisi et al., 2021). Grapes and kiwi peels, studied respectively by Auerbach George et al. (2022) and Rizzi et al. (2022), act as bio-sorbents, enhancing fabric properties such as moisture absorption and odour control. Milk proteins are processed into regenerated protein fibres, replicating silk and wool properties (Stenton et al., 2021). Peanut husks can be used for natural fibres or bio-based additives (Ţincu et al., 2021). Fish scales contribute to bio-based polyester fibres, offering sustainable alternatives to fossil-fuel-derived polyester (Hou et al., 2022). Citrus cellulose is integrated into bio-based fabrics, promoting renewable and breathable materials (Torrisi et al., 2023). Other studies explore food waste-derived bio-based textiles, showcasing the versatility of agricultural by-products (Alzaabi et al., 2023). Kombucha, rich in microbial cellulose, is another promising material for bio-based textiles (Provin et al., 2021). Additional innovations include pomegranate peel extracts and wood ash extracts, which enhance UV protection in bio-based garments through zinc oxide nanoparticle synthesis on cotton fabrics, eliminating the need for chemical treatments (Verbič et al., 2021). This process exemplifies a sustainable CE, where biological waste-derived materials are directly repurposed into functional and eco-friendly textile innovations. Furthermore, the concept of a circular food economy reinforces these efforts by utilizing food industry by-products to produce textiles, cosmetics, and biodegradable packaging. Widely discussed in scientific literature, this approach emphasizes the importance of closing material loops in food production processes, reducing waste and enhancing resource efficiency throughout the supply chain.

3.2.2. Synergistic industrial interaction between leather and other sectors

The leather processing sector not only plays a key role in the luxury industry but also serves as a valuable resource in advancing sustainability across multiple industries. Increasingly, companies are exploring innovative ways to repurpose leather processing by-products, transforming them into valuable inputs for diverse sectors.

In the energy industry, leather scraps can be converted into biofuels. Recent research (Turzyński et al., 2023), demonstrates that through thermal treatments and conversion processes, these scraps can be processed into biofuel pellets, providing a renewable energy source for heating and industrial applications, while also reducing carbon emissions and supporting the transition to sustainable energy.

In the chemical industry, leather serves as a rich source of protein hydrolysates. By using enzymes such as proteases, it is possible to convert leather proteins into hydrolysates used in fertilizers, chemicals, and animal feed protein supplements (Appala et al., 2022; Mahmood Ali et al., 2023), it is possible to convert leather proteins into hydrolysates used in fertilizers, chemicals, and protein supplements for animal feed. This not only improves waste management but also adds value to materials previously considered mere waste. Considering chemical waste utilization in the leather industry, significant innovations have emerged. For example, Venkatachalam et al. (2022) studied the use of bacterial strains for bio-leather production, promoting sustainable solid waste management in tanning processes. This method utilises Bacillus sp. KLP1 to convert proteins and biological waste into biodegradable leather, offering an eco-friendly alternative to conventional tanning treatments. Similarly, Schiros et al. (2022) explored the use of nanocellulose to develop sustainable bio textiles with a circular lifecycle. By treating nanocellulose with lecithin, they produced compostable materials with superior mechanical properties, improving strength and ductility in bio-leather. These advancements illustrate how collaboration between chemistry and the leather processing can drive the development of high-performance, sustainable materials. Additionally, the chemical industry employs leather-derived bio-sorbents and collagens for industrial wastewater purification and medical applications, leveraging leather's natural properties to enhance environmental sustainability (Appala et al., 2022; Mahmood Ali et al., 2023).

Beyond these sectors, synergies between the food and leather industries are opening new opportunities in bio-leather production. Traditionally considered waste, fish skin from aquaculture has proven to be a promising raw material for bio-leather manufacturing (Fadda et al., 2023). Due to its unique microstructure, fish skin offers an ecological alternative to conventional leather production methods. Similarly, food industry by-products, such as peels, seeds, and organic residues, can be valorised into high-quality bio-leather through sustainable processes (Kumari et al., 2023).

3.2.3. Synergistic industrial interaction between fashion and other sectors

Another notable synergy exists between the fashion and construction sectors. Neri et al. (2021) investigate the reuse of clothing to produce acoustic panels, mixing them with end-of-life household materials such as cardboard, egg cartons, and metal scraps. This approach enables the low-cost production of acoustic panels, making them accessible to low-income communities. By strategically combining discarded materials, these panels achieve good acoustic performance with limited thickness. Conversely, construction waste can serve as a valuable input for the fashion industry. Indrie et al. (2023) explore the repurposing of mild steel scrap from construction sites to assess its coefficient of friction (COF) on cotton fabric, a key factor in CE practices for textile recycling. Based on COF values, deformation, wear, and morphology assessments, mild steel mechanical components could be operationally employed for textile waste recycling and surface alterations of textile machinery parts.

Synergies between the food industry and fashion highlight further sustainable innovations. The fashion sector, historically a major waste producer, is shifting towards sustainability by integrating food waste materials into fashion products. Recent studies propose biodegradable buttons made from food waste (J. Costa & Broega, 2023) and the recycling of discarded fishing nets, lines, and ropes into sustainable fashion items (Erasmus et al., 2024).

In line with the IS definition, textile waste from one company processing a specific raw material can serve as an input for another company producing a different product, even within the same broader sector but across different value chains. The fashion industry itself demonstrates this circular approach, with textile waste repurposed into new products. Chiengora, for example, utilizes dog combings to produce high-fashion garments (Motta et al., 2023). Similarly, cotton waste is repurposed into thermal clothing and durable denim, maximizing the potential of natural fibres (Bhuiyan et al., 2023). Synthetic fibres also find new applications. Polyester and other synthetics are transformed into protective gloves and garments, extending material lifespan and reducing the need for virgin resources (Bonifazi et al., 2022). Additionally, these materials are used in sustainable packaging solutions for the fashion industry (Mishra et al., 2022). Within the textile industry, fibre waste is recycled into felt backing for carpets, offering a sustainable alternative to petroleum-based materials (Shirvanimoghaddam et al., 2020). Further material innovations include recycling silk into generic yarns (Lu et al., 2022) and reusing alpaca fibres in composite textiles, enhancing insulating properties for outerwear and high-performance fabrics (Al Faruque et al., 2020). Textile waste, including scraps and unused materials, can also be converted into activated carbon, a bio-sorbent widely used for water purification and air filtration in the fashion industry (Parmakoğlu et al., 2023). Giehl et al. (2024) explore combining leather with thermoplastic polyurethane to create shoe soles, improving footwear performance while reducing environmental impact.

In conclusion, based on the findings from the literature review, a new database has been developed to map input resources derived from waste and the possible outputs generated from these inputs. Table 2 consolidates this evidence, summarizing key synergies identified across industries within the IS framework. Specifically, it outlines the industries involved and provides detailed insights into the exchanged inputs and outputs. This comprehensive data collection enables the analysis of potential synergies across various industries, with a particular focus on fashion, textile, and leather sectors. By leveraging these insights, companies can enhance CE practices, reduce costs, and minimize environmental impacts, fostering a more sustainable industrial ecosystem.

4. Semi-structured interviews results

In this section, the findings from the literature review are further analysed through multiple case studies, based on five semi-structured interviews, as detailed in the methodology section.

To obtain empirical insights on the identified synergies, the literature review results were discussed and validated through interviews with companies already engaged in IS networks, though not necessarily within the fashion sector. As a starting point, the input–output matches framework presented in Table 2 was evaluated in terms of coherence and completeness, with company responses summarizes in Fig. 5 (i.e., numbers indicate the positive responses for each match). The sampled companies demonstrated awareness of most of the identified input–output exchanges, recognizing 13 out of 22. However, nine exchanges were new to all participants, and one additional exchange—Mining to Fashion—was introduced by Company A. This suggests that while the existing literature provides an extensive overview, some exchange opportunities remain unexplored by practitioners.

During the interviews, several key aspects of IS were discussed, including companies' awareness of IS networks, their understanding of IS principles, the processes they followed to establish or participate in IS collaborations, and their perceived needs for enhancing resource exchanges. Below is a summary of the findings for each company.

Despite implementing IS principles in its production process, *Company A* was unaware of the IS concept and did not recognize its operations as part of an IS framework. The company discovered the potential

Table 2
Input-output exchanges in IS.

Industries	Input	Output	Reference
Agricultural to Fashion	Fungal Mycelium	Bio-Based Garment Bio-Based Packaging	(Cerimi et al., 2019)
Agricultural to Leather	Fungal Mycelium	Bio-Based Leather	(Cerimi et al., 2019)
Agricultural to Textile	Algae	Bio-Sorbent	(González Fernández et al., 2023)
	Coconut Waste	Sewing Thread	(Ghamari et al., 2024)
	Raw Palm Waste	Bio-Sorbent	(Azoulay et al., 2022)
Chemical to Leather	Bacterial Strain	Bio-Based Leather	(Venkatachalam et al., 2022)
	Nanocellulose	Bio-Based Leather	(Schiros et al., 2022)
Construction to Textile	Mild Steel Material	Fabrics	(Hussain et al., 2021)
Fashion to Construction	Garment	Acoustic Panels	(Neri et al., 2021)
Food to Fashion	Fishing items (e.g., finishing nets)	Clothing	(Erasmus et al., 2024)
	Fishing items (e.g., finishing nets)	Footwear	(Erasmus et al., 2024)
	Food (Generic)	Bio-Based Packaging	(Alzaabi et al., 2023)
		Biodegradable Button	(J. Costa & Broega, 2023)
	Pomegranate Peel Extract Wood Ash Extract	UV Protective Bio-Based Garment	(Verbič et al., 2021)
Food to Leather	Fish Scales	Bio-Based Leather	(Fadda et al., 2023)
	Food (Generic)	Bio-Based Leather	(Kumari et al., 2023)
Food to Textile	Citrus Cellulose	Bio-Based Fabrics	(Hou et al., 2022) (Torrisi et al., 2023)
	Dried Corn Husks	Bio-Based Colouring Pigments	(De Nisi et al., 2021)
	Fish Scales	Bio-Based Fabrics	(Hou et al., 2022); (Torrisi et al., 2023)
		Bio-Based Polyester Fibre	(Hou et al., 2022)
	Food (Generic)	Bio-Based Fabrics	(Alzaabi et al., 2023)
	Grape	Bio-Sorbent	(Auerbach George et al., 2022)
	Kiwi Peels	Bio-Sorbent	(Rizzi et al., 2022)
	Kombucha	Bio-Based Fabrics	(Provin et al., 2021)
	Milk	Regenerated Protein Fibre	(Stenton et al., 2021)
	Nutmeg Shell	Bio-Sorbent	(Vaishna et al., 2023)
	Peanut Husks	Regenerated Protein Fibre	(Ţincu et al., 2021)
Leather to Agricultural	Tannery Fleshing Waste	Fertilizers for Agriculture	(Islam et al., 2024)
Leather to Chemical	Leather	Bio-Sorbent Collagen Protein Hydrolysate	(Appala et al., 2022); (Mahmood Ali et al., 2023)
Leather to Energy	Leather	Bio-Fuel Pellets	(Turzyński et al., 2023)
		Biogas	(Appala et al., 2022); (Moktadir et al., 2020)
Leather to Fashion	Leather	Composite Materials for Shoes	(Giehl et al., 2024)
Textile to Agricultural	Polyester Fibres	Fertilizers for Agriculture	(Navone et al., 2020)
	Textile Fibres (Generic)	Fertilizers for Agriculture	(Biyada & Urbonavičius, 2025)
	Textile Fibres (Generic)	Biodegradable Water-Absorbing Geocomposites for Agriculture	(Marczak et al., 2023); (Marczak et al., 2024)
	Viscose Textile Waste	Absorbents for Pesticide Removal from Water	(Tasić et al., 2025)
	Wool	Fertilizers for Agriculture	(Zoccola et al., 2015)
Textile to Chemical	Cotton	Bio-Based Materials for Chemical	(Vera et al., 2022)
		Glucose	(Vera et al., 2023)
	Textile Fibres (Generic)	Chemical Feedstocks	(Barla et al., 2017); (Voncina et al., 2018)
		Aromatic Hydrocarbons	(Wang et al., 2022)
Textile to Construction	Cotton	Sugar-Based Block Copolymers	(Vera et al., 2023)
	Silk	Reinforcement	(Lu et al., 2022)
	Synthetic Fibres	Cement Mortar	(Marinelli et al., 2022)
	Textile Fibres (Generic)	Aerogel	(Linhares et al., 2023)
		Asphalt	(Landi et al., 2018)
		Building Applications	(Lu et al., 2022)
		Composite Panels	(Antolinc & Filipič, 2021); (Lahtela et al., 2021); (Lamoudan et al., 2024)
		Glass Foams	(Cozzarini et al., 2023)
		Interior Decoration	(Indrie et al., 2023)
		Thermal Insulator	(Augello et al., 2022); (Biyada et al., 2023)
		Thermosetting Resins	(Patti et al., 2021)
		Vapor Barrier Coatings	(Salah et al., 2022)
	Wool	Composite Panels	(Rubino at al., 2019)
Textile to Energy	Textile Fibres (Generic)	Energy	(Athanasopoulos & Zabaniotou, 2022); (Biyada & Urbonavičius, 2025); (Papamichael et al., 2024)
		Fuel Pellets	(Kramens et al., 2023)
	Silk	Energy	(Lu et al., 2022); (Papamichael et al., 2024)
Textile to Fashion	Chiengora	Bio-Based Garment	(Motta et al., 2023)
	Cotton	Denim	(Dorogan et al., 2023)
		Garment	(Vera et al., 2022)

(continued on next page)

Table 2 (*continued*)

Industries	Input	Output	Reference
		High-Performance Thermal Garment	(Bhuiyan et al., 2023)
	Polyester Fibres	Garment	(Bonifazi et al., 2022)
		Protective Gloves	(Irfan et al., 2022)
	Textile Fibres (Generic)	Garment	(Bonifazi et al., 2022)
		Packaging	(Mishra et al., 2022)
Textile to Food	Textile Fibres (Generic)	Glucose Syrup	(To et al., 2019)
Textile to Paper	Textile Fibres (Generic)	Paper	(Shirvanimoghaddam et al., 2020)
Textile to Sports and Fitness Equipment	Textile Fibres (Generic)	Fill Materials for Punching Bags	(Espinoza-Pérez et al., 2024)
Textile to Textile	Alpaca Fibres	Composite Fibres	(Al Faruque et al., 2020)
	Silk	Yarn (Generic)	(Lu et al., 2022)
	Textile Fibres (Generic)	Cellulosic Fibres	(C. Costa et al., 2022)
		Felt Backing for Carpet	(Shirvanimoghaddam et al., 2020)
	Textile Waste in Activated Carbon	Bio-Sorbent	(Parmakoğlu et al., 2023)

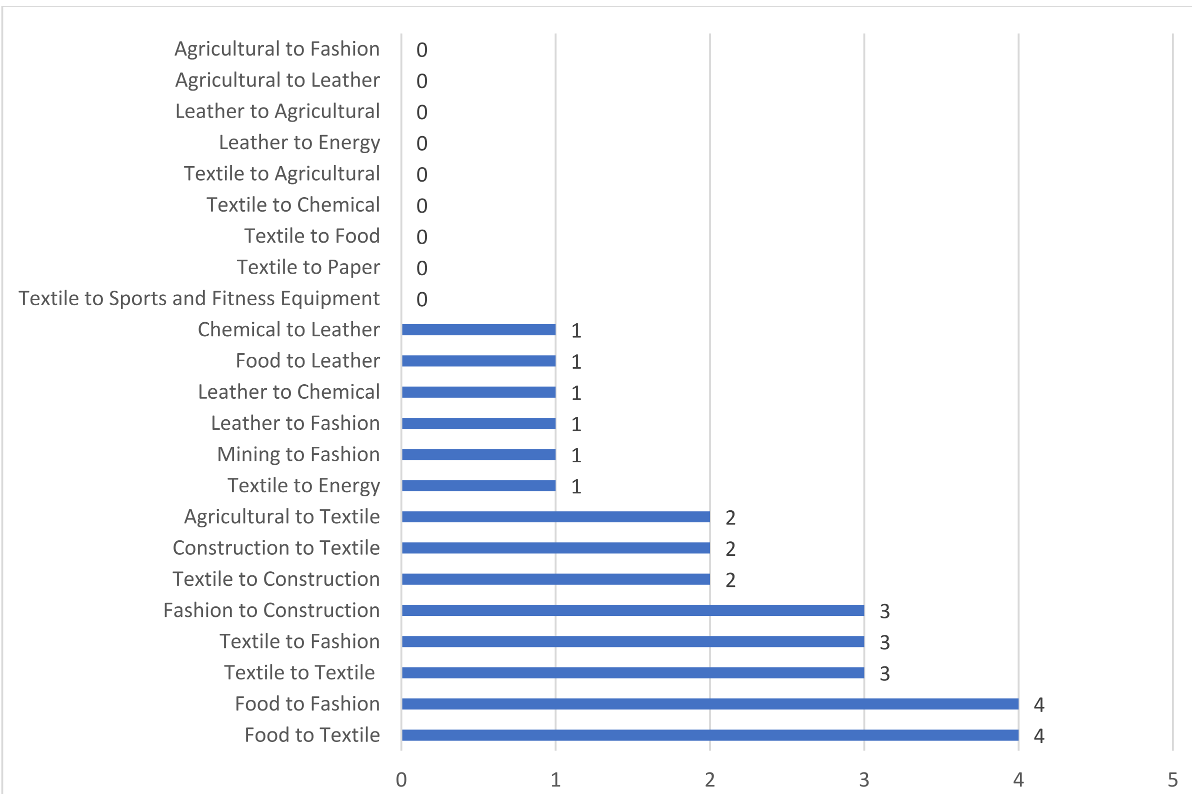

Fig. 5. Framework validation responses summary.

to repurpose marble waste for enhanced textile performance, such as waterproofing, through a university research project. Based on its experience, the company evaluated potential synergies between textiles and energy, construction and textiles, and food and textiles. While intermediaries are not yet utilized, the company considers their role crucial in expanding connections between value chains. Additionally, it emphasized the importance of digital platforms that help companies visualize potential outputs from waste exchanges, including associated costs and environmental impacts.

Company B was well-versed in IS principles and established an IS-based synergy through its internal Research & Development (R&D) department, which identified how pineapple leaves, once considered waste, could be used to create luxury bags for the fashion industry. The company recognizes various additional synergies, including between textiles and construction, leather goods, energy, and chemicals, as well as chemical and leather industries. It also sees potential in using agricultural and chemical residues in textiles, food waste in apparel, and apparel waste in construction. The company emphasized the crucial role of intermediaries in facilitating resource exchanges and strengthening relationships across diverse value chains. These intermediaries support knowledge sharing, information dissemination, and network expansion, enabling new synergies and fostering cross-sector collaboration. Additionally, the company stressed the importance of a digital platform to map waste inputs and potential outputs, streamlining decision-making for manufacturing managers. It also highlighted the need for cost, benefit, and environmental impact visibility to guide resource exchange decisions. Finally, based on the input–output framework presented, the company expressed its intent to develop future synergies with the fashion sector.

Company C considers IS a key driver for its business and demonstrated a clear understanding of IS principles. It identified new product opportunities from specific waste through market research, investing time in finding the right material matches. It currently repurposes waste from fruit juice processing (primarily apples) and bamboo forest pruning to create alternative materials to animal leather. To establish these synergistic relationships, it engaged in direct collaborations with specific companies. However, the company highlighted the lack of effective IS platforms and stressed the need for digital tools and external intermediaries to facilitate exchanges. According to the company, an IS-based platform would have greatly streamlined decision-making, reducing research and development time. The company sees strong synergies across industries, particularly textile-construction, textile-clothing, food-leather, and food-clothing. Additionally, it recognizes potential exchanges from agriculture and clothing to textiles and from clothing to construction. All identified synergies align with those highlighted in the literature review and incorporated into the framework.

Company D recognizes the potential of IS-based exchanges, with its understanding of IS opportunities reinforced through business networks and industry associations. Through market research and scientific studies, the company evaluated how to develop new products from specific waste streams. It currently manages the drying of coffee grounds collected from food industries, working in collaboration with social cooperatives. The company sees its primary exchange opportunity between the food and chemical sectors but also identifies future potential in the fashion sector for developing bio-based products. During the interview, Company D emphasized the importance of intermediaries in facilitating connections, fostering synergies, and increasing IS visibility. While it has established direct IS collaborations without intermediaries or platforms, it acknowledged that intermediaries could enhance networking and support new partnerships. Additionally, the company highlighted the need for digital platforms that allow businesses to input waste types and explore potential outputs, streamlining the evaluation of innovative IS opportunities. Looking ahead, Company D intends to expand collaborations in the automotive, construction, chemical, food, and clothing sectors.

Company E has a deep understanding of IS networks, as its entire business model is based on Industrial Symbiosis principles. This knowledge stems from scientific and technical studies, collaborations with research institutes, and internal expertise. The company actively participates in CE projects, producing bio-based design products from food waste. To establish synergies, Company E has independently engaged with other businesses, without relying on intermediaries. However, it acknowledges the crucial role of intermediaries in facilitating initial connections, particularly when they have direct access to relevant industry players. The company also emphasizes the importance of digital platforms, enabling businesses to input waste types and explore potential output applications and identify which inputs can generate specific sustainable outputs. It considers it essential for such platforms to integrate cost, benefit, and environmental impact data to support decision-making in IS adoption. Currently, Company E is exploring new IS-based collaborations and plans to expand its biopolymer production capacity, increasing the conversion of by-products into high-value materials. Food waste could be repurposed into buttons and accessories for the fashion industry, while textile by-products (wool, cotton, leather) could be used to develop bio-polymers. Additionally, agricultural by-products (e.g., cereal waste, fennel scraps) could be transformed into furniture items, cosmetic caps, and electronic device covers. This expansion aims to reduce costs, enhance biopolymer affordability, and make IS processes more efficient and profitable.

Table 3 summarizes the relationships observed for the sampled companies, considering both current and potential outputs.

Table 3
Input-output exchanges for the sampled companies.

Industries	Input	Current output	Potential future outputs	Reference
Food to Chemical	Coffee Grounds		Bio-polymers	Company D, Company E
	Lemon Peels		Bio-polymers	Company E
	Orange Peels		Bio-polymers	Company E
Food to Design	Coffee Grounds	Design Objects		Company D, Company E
	Lemon Peels	Design Objects		Company E
	Orange Peels	Design Objects		Company E
Food to Fashion	Apple Waste		Bio-Based Garment	Company C
	Coffee Grounds		Buttons and Fashion Accessories	Company D, Company E
	Lemon Peels		Buttons and Fashion Accessories	Company E
	Orange Peels		Buttons and Fashion Accessories	Company E
	Pineapple Leaves		Bio-Based Garment	Company B
Food to Leather	Apple Waste	Bio-Based Leather		Company C
	Pineapple Leaves	Bio-Based Leather		Company B
Food to Paper	Apple Waste	Bio-Based Bookbinding		Company C
Mining to Fashion	Marble Powder	Waterproof Fabric		Company A

5. Discussions

Starting from the evidence from the literature review and the interviewed companies, shown in Table 2 and Table 3 respectively, the waste flows between different types of industries were identified. Table 4 summarizes the number of input–output exchange opportunities within IS involving the fashion ecosystem, highlighting the total Industry-to-Industry exchanges identified. The construction and food industries are the most involved in IS within the fashion ecosystem. The research identifies 14 exchanges where the construction industry utilizes waste, specifically 13 from textiles and one from fashion. Meanwhile, the food sector serves as a major waste provider, contributing to 21 exchanges, with 11 directed to textiles, six to fashion, and four to leather. Besides, Table 5 presents the number of inputs and outputs per industry involved in IS for the fashion ecosystem, emphasizing which industries are most involved in providing waste for reuse, utilizing waste as an input, or both. For instance, the food industry is primarily involved as an input provider, the construction and fashion industries as output receivers, while the textile industry plays a role in both providing and utilizing waste.

Several detailed opportunities for repurposing process and product wastes and generating sustainable outputs have emerged. Appendix B summarizes these opportunities, illustrating where the same waste input can be used to produce multiple outputs and, conversely, where the same output can be derived from different waste inputs. Taking as an example, fish scales can be used to create three distinct outputs, while fertilizers for agriculture can be produced from four different types of waste. This information is particularly valuable for companies operating in the identified input sectors, as it highlights numerous opportunities to maximize the value of their waste. It enables them to assess whether their waste materials can be effectively repurposed as inputs for other industries, optimizing resource utilization and fostering CE practices. To provide a deeper understanding of which types of outputs can be generated from a single input and, conversely, which types of waste can be used as inputs for other production processes, Table 2 presents a detailed database of potential input–output exchange opportunities. While Appendix B serves as a strategic entry point, offering a broader overview of waste valorisation pathways, Table 2 should be consulted for a comprehensive breakdown of specific input–output combinations.

Table 4
Overall input–output exchanging opportunities between industries.

			Output										
			Agricultural	Chemical	Construction	Energy	Fashion	Food	Leather	Mining	Paper	S&FE*	Textile
		Tot I/O	*6*	*7*	*14*	*5*	*18*	*1*	*7*	*0*	*1*	*1*	*20*
Input	Agricultural	*6*	–	–	–	–	2	–	1	–	–	–	3
	Chemical	*2*	–	–	–	–	–	–	2	–	–	–	–
	Construction	*1*	–	–	–	–	–	–	–	–	–	–	1
	Energy	*0*	–	–	–	–	–	–	–	–	–	–	–
	Fashion	*1*	–	–	1	–	–	–	–	–	–	–	–
	Food	*21*	–	–	–		6	–	4	–	–	–	11
	Leather	*7*	1	3	–	2	1	–	–	–	–	–	–
	Mining	*1*	–	–	–	–	1	–	–	–	–	–	–
	Paper	*0*	–	–	–	–	–	–	–	–	–	–	–
	S&FE*	*0*	–	–	–	–	–	–	–	–	–	–	–
	Textile	*41*	5	4	13	3	8	1	–	–	1	1	5

*Sports and Fitness Equipment.

Table 5
Overall inputs and outputs involved in IS for the fashion ecosystem.

Industry	#Inputs for IS	#Outputs from IS
Agricultural	4	3
Chemical	2	7
Construction	1	13
Energy	0	4
Fashion	1	12
Food	15	1
Leather	2	1
Mining	1	0
Paper	0	1
Sports and Fitness Equipment	0	1
Textile	10	12

This structure facilitates informed and strategic decision-making for industries aiming to enhance their CE practices. Unlike previous studies that focused on single input–output exchanges, this study provides a broader, network-based perspective on resource flows within IS systems, rather than concentrating solely on the structural characteristics of these networks. For instance, the numerous synergies between textile, food, and construction, as outlined in Table 4, can be further explored through the detailed input–output exchanges in Table 2. The food industry supplies various valuable inputs to the textile sector, such as citrus cellulose, dried corn husks, fish scales, grape, kiwi peels, kombucha, milk, nutmeg shell, and peanut husks. Conversely, the construction sector utilizes textile-derived inputs, including wool fibres, to produce high-value outputs such as aerogel, asphalt, composite panels, glass foams, thermal insulators, vapor barrier coatings, and other building applications. These findings have significant theoretical implications, as the iterative process enabled the categorization of waste types for exchange and the identification of the sectors involved in these exchanges. Hence, this contribution facilitates the identification of matching opportunities, supporting waste valorisation within an IS network where the fashion ecosystem places the primary role. Given the multiple connections between different industries, there are numerous opportunities for resources exchanges, although in practice the participation in or the establishment of IS networks still appears to be limited.

Looking at the semi-structured interviews results, it was possible to investigate through empirical evidence how companies engaged in IS perceive these synergies, offering initial validation of the framework developed from the literature review. All interviewees confirmed the existence of the identified resource flows, with Company A introduced a new synergistic industry—mining—beyond the literature findings. Additionally, Company B and Company C identified new types of food waste for bio-leather production, specifically apple waste and pineapple leaves. Furthermore, the involved companies demonstrated synergies extending beyond the fashion sector, such as food to design for Company D and Company E and food to paper for Company C. These findings suggest that applying similar analyses to other industries could uncover further IS opportunities. However, companies acknowledged limited awareness of potential synergies, as most IS projects have been internally developed by their R&D departments (i.e., Company B, Company C, and Company D). Only a few firms relied on external collaborations, such as with universities (i.e., Company A and Company E) through regional, national, or European funded projects. Most projects remained highly focused on regenerating specific waste types, without exploring broader resource exchanges. To broaden IS adoption, external intermediaries could play a key role. While internal R&D efforts have delivered valuable outcomes, intermediaries and input–output matching platforms would allow companies to save time and access a wider range of resource exchange opportunities. Indeed, the creation of well-monitored input–output platforms, managed by intermediaries, could be a turning point for expanding IS adoption. These platforms would enhance value chain connections, optimize resource utilization, and extend the lifecycle of materials. Indeed, from a practical point of view, the input–output exchange database may represent the basis upon which to develop these platforms. The majority of interviewees emphasized the need to integrate quantitative data into these input–output platforms, including economic and environmental performance metrics. This information would help companies assess the feasibility of IS partnerships in advance. Additionally, these platforms could help balance supply and demand by pooling waste materials from multiple companies, ensuring sufficient volumes for industrial reuse.

6. Conclusions

This research highlights opportunities for resource exchange between the fashion ecosystem and various industries, including agriculture, chemicals, construction, energy, paper, and food, as well as synergies within textile, fashion, and leather sectors. The development of an input–output matching list provides a structured approach for waste producers to find suitable outlets and for industries to source materials sustainably. Additionally, several exchange options identified in literature were confirmed through industry interviews, emphasizing the need for dedicated platforms managed by intermediaries to facilitate collaboration and extend resource lifecycles.

6.1. Theoretical and practical contributions

From a theoretical perspective, this study fills an existing gap in IS research by providing a comprehensive analysis of potential IS networks centred on the fashion ecosystem. The literature review structured a detailed list of input–output exchanges, categorizing industries, recoverable wastes, and obtainable outputs across various sectors. Additionally, the interviews enabled the discovery and conceptualization of new synergies, while also validating and integrating those previously fragmented in the literature or not yet disseminated across various industrial actors. Indeed, case studies further introduced additional input–output exchanges beyond those documented in literature, demonstrating how real-world applications extend beyond established theoretical frameworks and contribute to the expansion of IS strategies. Specifically, while prior research already documents "Food to Leather" exchanges, our case studies reveal new material flows: Company C processes apple waste, and Company B uses pineapple leaves as inputs to produce bio-based leather. Additionally, the study uncovers entirely new cross-industry exchanges that were not previously explored. Notably, both Company D and Company E illustrate examples of "Food to Design" exchanges, Company C demonstrates "Food to Paper" synergies, and Company A introduces an innovative "Mining to Fashion" pathway. These findings underscore how empirical insights contribute to expanding IS opportunities beyond those captured in existing research. Therefore, from a theoretical point of view, the combined use of scientific research and industrial interviews enabled the uncovering of synergies not previously addressed in the literature.

From a practical perspective, this research identifies key synergies across value chains involving the fashion ecosystem, mapping specific resource exchanges between industrial networks. While existing studies primarily focus on linear exchanges within a single external value chain, our analysis broadens this perspective by uncovering alternative resource substitutions that enable the creation of new products and foster multiple exchange opportunities across industries. For example, our findings highlight its potential applications of textile fibre waste across multiple sectors: in the construction industry, it can be used for asphalt, composite panels, glass foams, and thermal insulators; in the chemical sector, it can serve as chemical feedstock; and in the energy sector, it can be converted into fuel pellets. At the same time, the study reveals that the same output a company aims to produce can be derived from different types of waste. For instance, bio-sorbents, commonly used for water purification, can be obtained from agricultural waste such as algae, but also from food processing discards, like nutmeg shells, grape residues, and kiwi peels. By broadening input–output interactions, this research highlights untapped opportunities for resource valorisation, helping industries transition from isolated exchanges to integrated circular production strategies.

6.2. Limitations and future research directions

While providing valuable insights into IS opportunities, this study presents some limitations that open avenues for further research.

One key limitation is the lack of a quantitative assessment of the economic and environmental benefits of input–output exchanges. Future studies should focus on developing models to measure these impacts, enabling practitioners to assess the feasibility of IS partnerships based on resource characteristics, exchange potential, and geographical proximity. By integrating such analyses, decision-makers could make more informed choices, ensuring that IS strategies align with both sustainability goals and economic viability.

Another limitation lies in the generalizability of the findings, as the empirical data collected through case studies remains limited. Expanding the number of industrial case studies and incorporating secondary data sources would strengthen the robustness of the proposed input–output matching framework. A broader empirical investigation would allow for a more comprehensive understanding of resource exchange dynamics and improve the applicability of IS strategies across different industrial contexts. Ensuring a wider dataset would also facilitate the identification of additional synergies that may not have been previously considered.

Moreover, this study focuses on the fashion ecosystem, given their high resource consumption and pressing need for sustainable solutions. However, future research should explore IS opportunities in other industries that heavily depend on critical raw materials, such as electronics. Expanding the scope of analysis to different industrial ecosystems would help identify tailored resource exchange mechanisms and develop strategies to scale up IS initiatives beyond the fashion sector.

Additionally, building on the identified input–output exchanges, future research should aim to develop decision-support tools that facilitate the effective reallocation of materials at the end of their lifecycle. These tools could help industry practitioners, policymakers, and intermediaries, such as industry associations and innovation hubs, by providing clearer pathways for resource recovery and reintegration into new value chains. Decision-support systems could also aid in optimizing IS network formation, ensuring that companies can easily identify and engage in sustainable exchanges.

Lastly, the successful implementation of IS initiatives depends on stronger collaboration among multiple stakeholders. Regulatory bodies play a crucial role in creating policies that incentivize IS adoption, while intermediaries are essential for facilitating cross-industry collaboration and fostering new synergies. Researchers contribute by providing data-driven insights to optimize resource exchanges and assess their impacts. Strengthening coordination among these actors is essential to overcoming institutional and operational barriers, ensuring that IS practices move beyond isolated case studies to become widespread industrial practices.

Addressing these research directions would contribute to the advancement of IS implementation, supporting the transition toward more sustainable and circular resource exchange ecosystems through a multi-stakeholder approach.

CRediT authorship contribution statement

Federica Acerbi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Virginia Fani:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Romeo Bandinelli:** Writing – review & editing, Supervision. **Marco Taisch:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

The interview protocol adopted to conduct the semi-structured interview is the following:

1) *Do you know which are the possible matches between the fashion sector with other sectors? In particular, do you know whether some waste from the fashion sector can be exploited in other sectors and vice versa whether some waste from other sectors can become a valuable input for the fashion sector?*
2) *How did you recognise the possible exchange of resources with the other sector?*
3) *How did you create your network?*
4) *According to your experience, what would have boosted the creation of your IS network and what may foster the creation of similar networks?*

Appendix B

Industry Input	Input	# Outputs
Agricultural	Algae	1
Agricultural	Coconut Waste	1
Agricultural	Fungal Mycelium	3
Agricultural	Raw Palm Waste	1
Chemical	Bacterial Strain	1
Chemical	Nanocellulose	1
Construction	Mild Steel Material	1
Fashion	Garment	1
Food	Apple Waste	1
Food	Citrus Cellulose	1
Food	Dried Corn Husks	1
Food	Fish Scales	3
Food	Fishing items (e.g., finishing nets)	2
Food	Food (Generic)	4
Food	Grape	1
Food	Kiwi Peels	1
Food	Kombucha	1
Food	Milk	1
Food	Nutmeg Shell	1
Food	Peanut Husks	1
Food	Pineapple Leaves	1
Food	Pomegranate Peel Extract	1
Food	Wood Ash Extract	1
Leather	Leather	6
Leather	Tannery Fleshing Waste	1
Mining	Marble Powder	1
Textile	Alpaca Fibres	1
Textile	Chiengora	1
Textile	Cotton	6
Textile	Polyester Fibres	3
Textile	Silk	3
Textile	Synthetic Fibres	1
Textile	Textile Fibres (Generic)	22
Textile	Textile Waste in Activated Carbon	1
Textile	Viscose Textile Waste	1
Textile	Wool	2

Industry Output	Output	# Inputs
Agricultural	Absorbents for Pesticide Removal from Water	1
Agricultural	Biodegradable Water-Absorbing Geocomposites for Agriculture	1
Agricultural	Fertilizers for Agriculture	4
Chemical	Aromatic Hydrocarbons	1
Chemical	Bio-Based Materials for Chemical	1
Chemical	Bio-Sorbent	1
Chemical	Chemical Feedstocks	1
Chemical	Collagen	1
Chemical	Glucose	1
Chemical	Protein Hydrolysate	1
Construction	Acoustic Panels	1
Construction	Aerogel	1
Construction	Asphalt	1
Construction	Building Applications	1
Construction	Cement Mortar	1
Construction	Composite Panels	2
Construction	Glass Foams	1
Construction	Interior Decoration	1
Construction	Reinforcement	1
Construction	Sugar-Based Block Copolymers	1
Construction	Thermal Insulator	1
Construction	Thermosetting Resins	1
Construction	Vapor Barrier Coatings	1
Energy	Bio-Fuel Pellets	1
Energy	Biogas	1
Energy	Energy	2
Energy	Fuel Pellets	1
Fashion	Bio-Based Garment	2
Fashion	Bio-Based Packaging	2
Fashion	Biodegradable Button	1
Fashion	Clothing	1
Fashion	Composite Materials for Shoes	1
Fashion	Denim	1
Fashion	Footwear	1
Fashion	Garment	3
Fashion	High-Performance Thermal Garment	1
Fashion	Packaging	1
Fashion	Protective Gloves	1
Fashion	UV Protective Bio-Based Garment	2
Fashion	Waterproof Fabric	1
Food	Glucose Syrup	1
Leather	Bio-Based Leather	7
Paper	Paper	1
Sports and Fitness Equipment	Fill Materials for Punching Bags	1
Textile	Bio-Based Colouring Pigments	1
Textile	Bio-Based Fabrics	4
Textile	Bio-Based Polyester Fibre	1
Textile	Bio-Sorbent	5
Textile	Fabrics	1
Textile	Regenerated Protein Fibre	2
Textile	Sewing Thread	1
Textile	Bio-Sorbent	1
Textile	Cellulosic Fibres	1
Textile	Composite Fibres	1
Textile	Felt Backing for Carpet	1
Textile	Yarn (Generic)	1

Data availability

Data will be made available on request.

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